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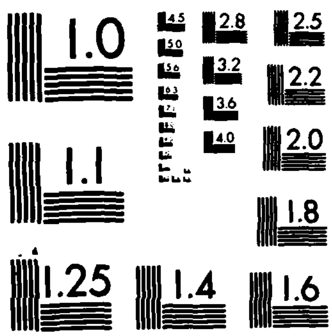

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FOREIGN TECHNOLOGY DIVISION

UNDERGROUND ENGINEERING
(Selected Articles)

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SUCCESSFUL TREATMENT OF SEVERE CAVE-IN OF WEATHERED BASALT LAYER BY AN ENGINEERING GROUP /25

Shen Junda and Wang Jingwen

A certain engineering group was in charge of the construction of an underground oil depot. It was necessary to excavate a 27.2 meter diameter large tank in the middle of severely weathered basalt. Cave-ins occurred frequently and the job was difficult. The excavation of such a span in this type of rocks was the first in that system. In the project, when the No. 4 tank was dug to a depth of 3.8 meters and the cap was already in place, the cap was fractured and collapsed in 126 degrees due to encountering a weak tuff layer. We successfully treated this large cave-in. In comparison to digging another tank, over one hundred thousand yuans of funding was saved. The work period was reduced by 50%. It provided some exploratory experience for similar underground engineering construction projects.

I. Situation of the Cave-in

In the excavation of the tank, a tuff layer was discovered. At the moment it was determined to clean the work surface and proceed with a support treatment. After the surface was cleaned, it was found that the exposed tuff layer on the surrounding wall was 16 m wide horizontally and 0.3 m thick. It penetrated through the surrounding rock wall into the tank at 1.8 m below the circular beam of the cap. Because it was discovered too late and was limited by the work surface, it was not able to adopt any support measure to prevent the collapse of the weak layer. Also because the circular beam of the cap was not enclosed, a 20 m long cantilever curved beam was created. In addition, the rocks were broken and the load on the cap continued to increase to cause the cap to fall by 126 degrees (Figure 1).

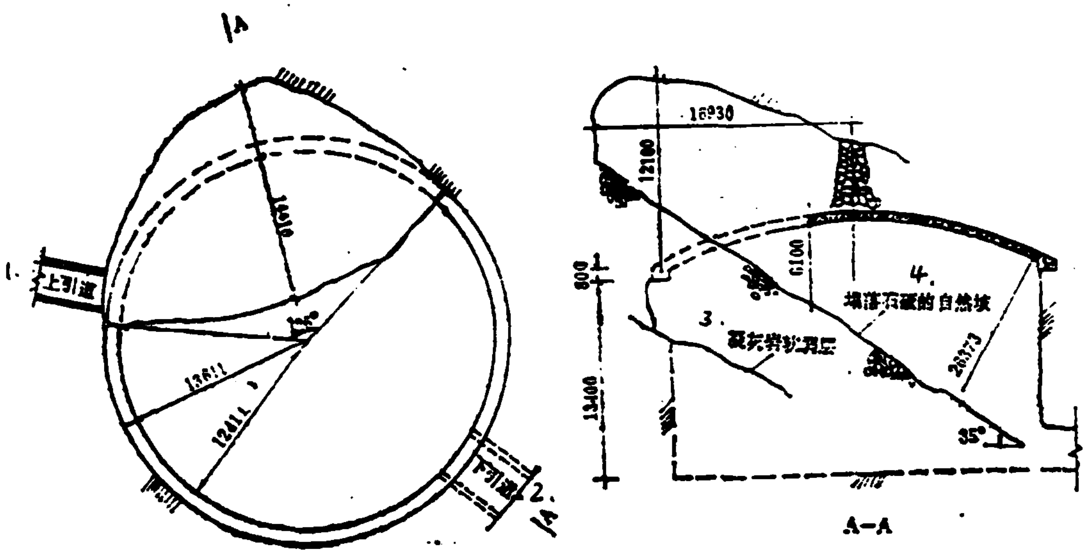

Figure 1

1. upper channel
2. lower channel
3. weak tuff layer
4. natural slope of the falling rocks

After the cap collapsed, the hanging area increased. In a certain range, the balance of stress on the surrounding rock was destroyed to cause the surrounding rock to lose equilibrium. Cave-ins occurred frequently. According to statistics, there were a total of 95 cave-ins. The surrounding rock was gradually stabilized after the stress was redistributed through natural collapses. In the situation that the effect of underground water on the surrounding rock was small and the vibration was not significant, the surrounding rock was stable within a certain period of time. The uncollapsed cap circular beam and surrounding rock were in a stable state. As long as the repair plan and measures were proper, the technology, manpower, and materials were ensured, and the organization and management were adequate, the repair could be made smoothly.

II. Repair Plan and Its Execution

Our superiors approved our three step repair plan to support the top, support the rock wall, and mend the cap, after repeated on-site surveys. Furthermore, an engineering group was dispatched to the location to provide guidance. Immediately afterwards, a repair command group consisting of 10 engineering leaders, engineers, and technicians were oganized. During the key stage of the repair work, the primary leaders of the command group stayed with the work team to allow the repair work to proceed smoothly.

(I) Support to Protect the Top

The objective of this step was to prevent the collapse of the hanging rocks to reduce the probability of rock falling and further cave-in to a minimum level. This was to ensure the safety in the operation to follow and to prevent the further deterioration of the cave-in. This was the key to the success of the entire repair project.

Because the falling rocks extended from 3.5 m from the highest point to the opening of the lower channel in a 35 degree natural slope, to erect wooden supports on such a steep slope was not only difficult to stabilize, but also difficult to work on. When workers worked on such a loose slope, large amounts of rocks had to slide downward to increase the height of the exposed rock wall. The equilibrium obtained under the condition that the rock wall was supported by the rock fragments would be destroyed. When the rock wall became unstable, cave-in would continue to occur. Consequently, the already stabilized redistributed stress on the surrounding rock at the top became unstable, leading to the possibility of larger cave-ins or even roof caving. The only way was to maintain the stability of the original natural slope of the rock fragments to prevent the further deterioration of the cave-in. It was determined to use a method to stabilize the sliding rock fragments by injecting a 1:4.5 cement to sand slurry. This maintained the original natural slope to create the condition for the top support work.

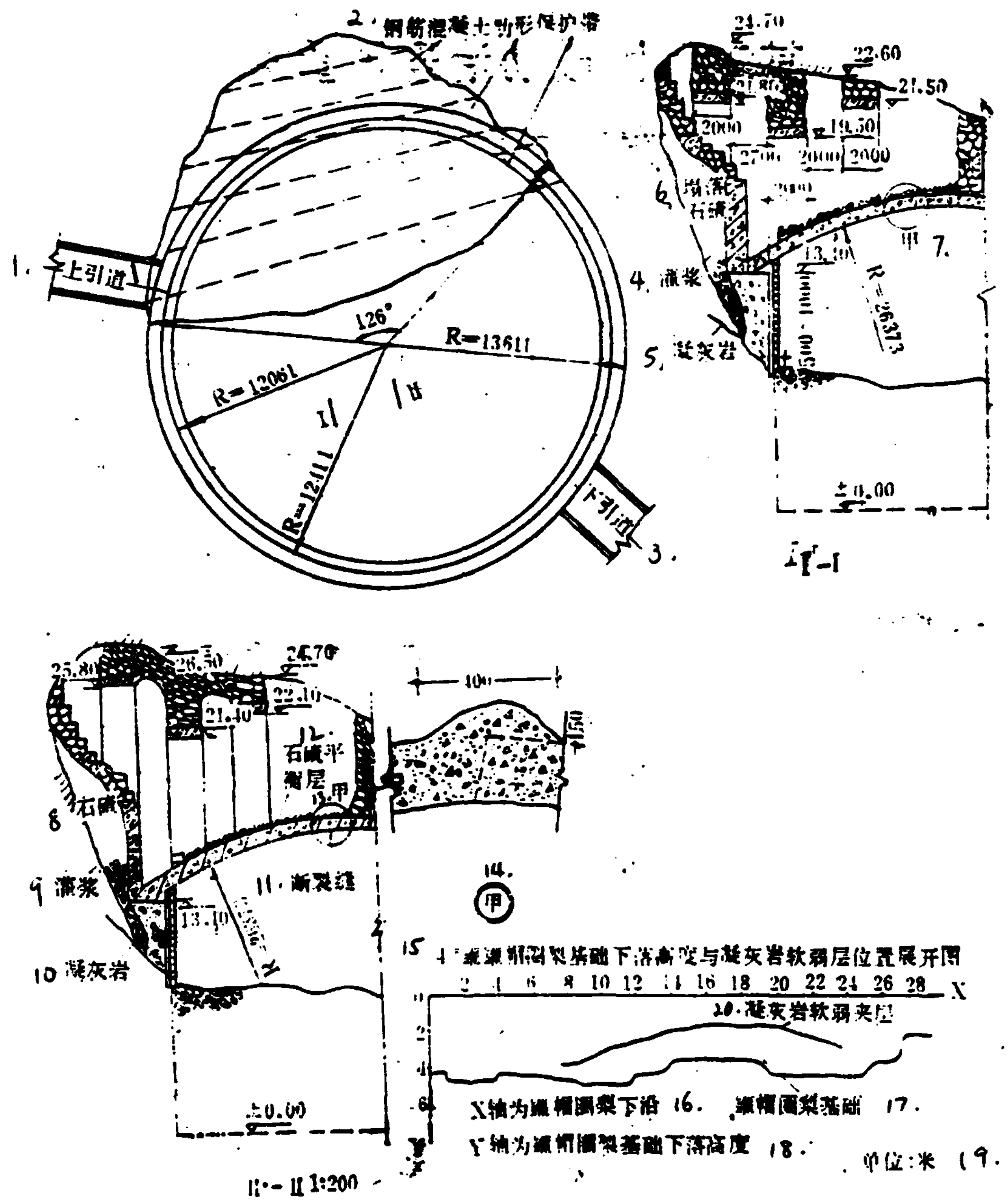

Figure 2

1. upper channel
2. steel reinforced concrete rib protection zone
3. lower channel
4. grouting
5. tuff

6. fallen rock fragments
7. A
8. rock fragments
9. grouting
10. tuff
11. fracture
12. rock fragment equilibrium layer
13. A
14. A
15. falling height of the foundation of the tank cap circular beam versus position of the weak tuff layer
16. X axis is the distance below the circular beam of the cap
17. foundation of cap circular beam
18. Y axis is the falling height of the foundation of the cap circular beam
19. unit: meter
20. tuff weakened layer

As for the top support work, due to the space limitation of a large area (the width of the cave-in was 22 meters, the height from the center of the cap to the farthest point of the collapsed /27 rock wall was 16.93 meters, and the height from the highest point of the cave-in to the cap circular beam was 12.10 m) and the requirements in practice, it was not possible to use densely located wooden supports. Instead, seven independent wooden poles were used to lean against the surrounding rock. In order to keep these independent wooden poles from becoming unstable due to excessively high forces, all the poles were tied up together by wood pieces over 0.30 meters in diameter. Furthermore, wood was used to fill the top of these poles so that they were leaning tightly against the surrounding rock. Among the seven wooden support poles, three were arranged below the cap fracture. The purpose was to prevent destructive deformation of the remaining 234 degrees of top cap due to excessive pressure.

The wooden pole top support work accomplished its projected objective. However, there were still some significant problems remaining. The difficulty of the next step, the excavation of the foundation of the circular beam, was high. Furthermore, the stability of the support (the seat of the seven wooden support poles was located on the 35 degree natural rock fragment slope), and the entirety of the cap circular beam could not be assured.

In addition, the area created by the cave-in was large and high. Whether the refilled tank cap, after it was repaired, would be destroyed again due to excessive pressure was another problem not to be ignored in the treatment of the cave-in. Summarizing the above factors, a permanent support must be considered. After repeated comparison, it was determined to build three 2m wide steel reinforced concrete rib-shaped protection belts parallel to the fracture. Their bases were higher than the cap circular beam and they were located on the base rock. Furthermore, cement blocks were used to fill up the surrounding rock. Between belts, arched bands were used to connect them at an interval of 2 to 3 meters. The wooden supports on the rib-shaped protection belts were replaced by cement blocks. This plan had good force bearing characteristics, and was economical. The construction was easy. Furthermore, it was able to bear the pressure from the surrounding rock early.

(II) Supporting the Rock Wall

In the top support work, through verification by practice, the possibility of cave-in and roof caving had been prevented. However, there was still some difficulty to directly excavate the foundation of the cap circular beam because a large amount of rock fragments had to slide downward during the excavation of the foundation of the circular beam. This not only increased the work load but also caused the rock wall to lose the support of the rock fragments. A cave-in due to instability would also occur. Consequently, it expanded the loose surrounding rock area and led the surrounding rock at the top to fall. Therefore, it was necessary to support the rock fragments at the top of the cap circular beam in order to create the condition for the excavation of the foundation of the circular beam. In the upper part of the cap, a stair type curved steel reinforced concrete retaining wall was built (every 2 meters) and a cement block curved retaining wall (grouted on the back of the retaining wall) were used to support the rock fragments and the rock wall. As for the treatment of the foundation of the cap circular beam, a method to excavate from top to bottom in many discrete steps

(opening less than 2m, height not more than 1m) was used. No. 150 concrete was used as the covering material. The foundation of the circular beam was secured on the base rock. The above treatment is shown in Figure 2.

(III) Mending the Cap

Becuase of the 4.5 meter high space between the debris and the circular beam, it was impossible to ensure the stability of the wooden support poles if independent wooden support frames were continued to be used. When the cap repair job was carried out, the coverage was put on circularly. Furthermore, in addition to a vertical pressure, there was a thrust toward the center of the tank with regard to the force acting on the frame and support. A 135 degree sector-shaped wooden frame was used as the support in order to prevent a significant deformation due to the thrust. As for the treatment of the seam of the new and old concrete at the fracture, a reinforcement treatment was done in addition to roughening and cleaning the surface (See Figure 2A). As for the mixing ratio, 10 kg of additional cement was added to each m^3 in order to increase its *strength*. After the job was done, the two rib-shaped protection belts at the top of the cap were treated with various reinforcing processes. Moreover, a 0.3~0.4 m thick layer of rock fragments was back filled on the cap for balancing and buffering to slow down the direct impact from the falling rocks on the cap.

III. Program Organization and Experience

According to the experience in treating cave-ins over the years, the first requirement is quickness and the next is prudence. Quickness is to reduce the time limit to treat a cave-in to a minimum. First, it is necessary to concentrate the manpower to form four groups to work on three eight hour shifts. The next is to require a sufficient backup in supplies. Whatever the materials needed for the repair job must be supplied in time. The third is to create a technical assurance group. Each group must be accompanied by 1~2 technical personnel in order to solve the technical problems encountered in time.

Prudence is to be scientific and to overcome blindness.

The first is analyze all the possible problems for each procedure throughout the process and formulate a work plan. During construction, the work plan must be rigorously obeyed. The second is to insist that the cadres must work with the group to ensure the quality. In key procedures (supporting the top, pouring the support, etc.), technical personnel and leading cadres must be with the group to ensure that the technical plans are accurately executed and the construction is done safely. Due to the attention given by various leading cadres and the proper measures taken in all aspects, no incident took place during the treatment of the cave-in of No. 4 cap.

After two years of observations, no deformation occurred at the cave-in site and the surrounding rock, indicating that the treatment plan was accurate. The construction quality was good.

INNOVATION IN INJECTION CONCRETE AGGREGATES /28

Hu Yexi

The use of injection concrete in the construction of civil defense projects has already obtained significant technological and economical results. As we all know that the strength, deformation, and durability of injected concrete are also related to the material composition and aggregate selection, in addition to the technological conditions. Hence, whether the aggregates of injected concrete can be chosen locally has an important significance in reducing the consumption of raw materials and lowering the engineering costs.

The key to the selection of local aggregates for injected concrete is to ensure the strength of the injected concrete. The city of Hangzhou sold a large amount of rocks, excavated over the long term construction of tunnels, to the relevant units to be used as foundations in construction projects. The rocks were not fully utilized. In order to save capitals to produce its own aggregates, these rocks were processed to crushed stones. However, it resulted in the accumulation of a large amount of powdered stone, which was difficult to utilize and wasteful to discard.

In order to find the scientific basis to utilize such powdered stones, concrete injection tests were carried out in the tunnels under construction by the Mechanical Bureau of Hangzhou.

I. Tensile Resistance Tests

Materials Ratio:

cement: powdered stone = 1:4 (the powdered stone contains 40% of 2-3 mm stones)

Loading Device and Experimental Results

After curing for 28 days, the injected layer showed no macroscopic cracks upon tapping. As shown in Figure 1: a hook was installed. A 10 cm thick layer of concrete was injected. After 60 days of curing, the 0.6 ton of material was hanging on the hook. The cable broke, while the hook remained intact. The injected layer showed no cracks.

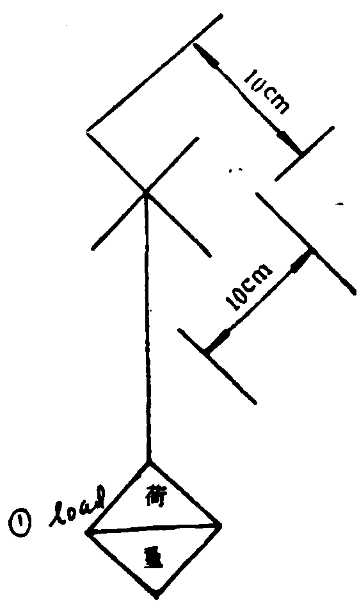

Figure 1

1. load

II. Destructive Tests

The materials ratio was the same as above.

Testing time: May 15, 1982

Loading Device and Experimental Results

The loading device was the same as above. No crack appeared with 3 tons of weight hanging on the aforementioned hook. Due to the fact that the load could not be further increased, the test was terminated for the duration.

The above experiment showed that the tension per m^2 could exceed 60 kg.

III. Test Block Experiment

The raw material was 500# silicate cement, its composition is as follows:

Results of Cement Analysis

calcined amount	3.73	free calcium saturation ratio	
silicon oxide	21.78	saturation ratio	0.761
aluminum oxide	5.54	silicate ratio	2.34
iron oxide	3.77	aluminate ratio	1.47
calcium oxide	56.89	tricalcium silicate	23.42
magnesium oxide	3.51	dicalcium silicate	44.77
sulfur oxide	1.74	tricalcium aluminate	8.29
total: 96.96		tetracalcium aluminoferrite	11.46

The chemical analysis of lime rock powder is as follows:

Analysis of Lime Rock Powder

calcined amount	41.63	free calcium saturation ratio	
silicon oxide	3.96	calcium carbonate	92.57%
aluminum oxide	1.29		
iron oxide	0.51		
calcium oxide	51.85		
aluminum oxide	0.67		
total: 99.90			

The particulate composition is shown in Figure 2.

The materials ratio and experimental results are shown in Table 1. These above experiments showed that: 1. the primary chemical composition of lime rock powder is calcium carbonate ($CaCO_3$), which occupied 92.5% (13% of the rock powder had a diameter less than 0.15 mm). These molecules react with tricalcium aluminate ($3CaO.Al_2O_3$) in the cement to produce calcium aluminocarbonate ($CaCO_3.3CaOAl_2O_3$). The chemical reaction is:

$CaO_3 + 3CaO.Al_2O_3 = CaO_3.3CaOAl_2O_3$, which has some effect to increase the strength of the concrete. On the contrary, the cement does not react with the coarser particles in the rock powder (sand) in the hydrolysis and hardening process. However, at a suitable water to sand ratio, the cement shrinks upon drying. The voids created after drying are occupied by the coarser particles in the powdered rock (sand) to increase the density of the concrete. Furthermore, the coarse particles in the rock powder are polygonal solids, while sand contains round crystals after being washed by water. Therefore, the binding effect of powdered rock in the concrete is larger than that of the sand. Correspondingly, the porosity of the concrete decreases. The structure is more compact and the strength is improved. According to tests conducted in limestone by the Portland Cement Company in the U.S., the tricalcium aluminate in the cement was found to react with calcium carbonate, in agreement with the results of our experiments. /29

2. The strength of the concrete using rock powder as the aggregate is basically the same as that of using sand. The strength of the concrete using rock powder, as a matter of fact, is slightly higher. Therefore, rock powder can replace sand.

3. The ratios of injected concrete are 1:4 = cement: rock powder (containing 40% fly head) and 1:2:2 = cement:sand: oval pieces. The pressure resistant strength is basically identical. Therefore, a rock powder containing 40% fly head can replace oval pieces.

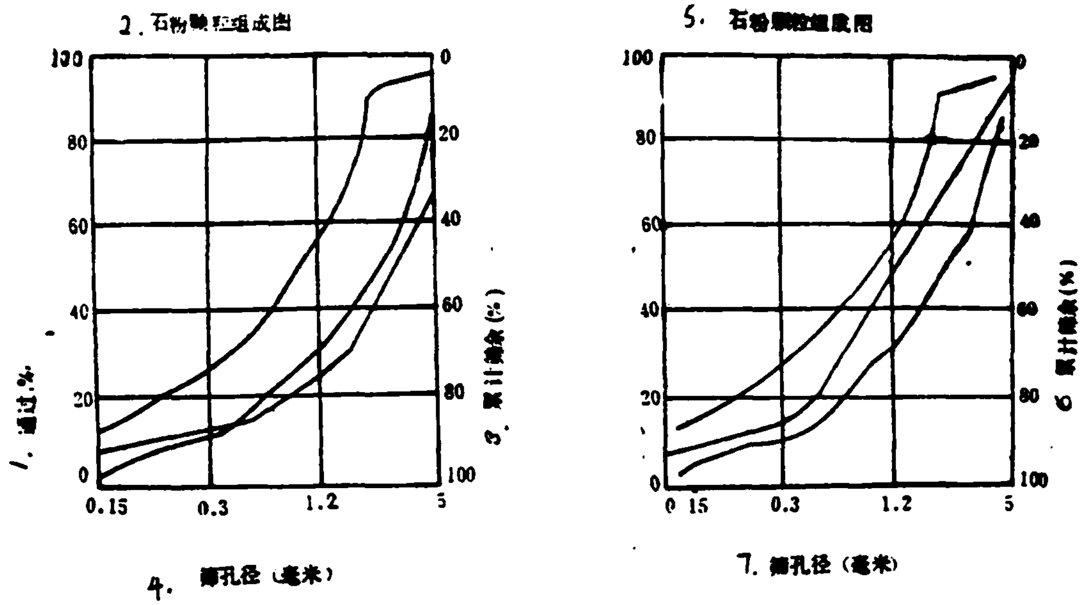

Figure 2.

1. passing through %
2. particle composition diagram of rock powder
3. cumulated amount remaining in the sieve (%)
4. sieve diameter (mm)
5. particle composition diagram of rock powder
6. cumulated amount remaining in the sieve (%)
7. sieve diameter (mm)

1. 水泥标号	2. 水泥	3. 石粉	4. 黄沙（中）	5. 瓜子片	6. 最大荷重（吨） 8. 7天	9. 14天	10. 28天	11. 35天	7. 抗压强度（公斤/厘米²） 7	14	28	35
12. 500 号 ‹普 通›	1	4						11.96				107.6
	1	2	2	2				17.6				158.6
13. 同 上	1	2		2	19.3	27.3	22.0		174	246	198	
	1		2	2	19.3	19	23.3		174	171	210	
14. 同 上	1	4			14.7	20.0	26.5		132	180	239	
	1		2	2	16.6	20.1	28.7		149	181	258	
15. 同 上	1	4			28.1	31.5	36.5		253	284	329	
	1		2	2	22.5	30.9	30.2		203	278	272	
16. 同 上	1	4			18.8	20.0	27.6		169	180	248	
	1		2	2	20.5	21.9	27.8		185	197	250	
17. 同 上	1	4			20.8	13.4	21.4		187	121	193	
	1		2	2	13.9	18.1	23.4		125	163	211	

Table 1. Comparison of Load and Pressure Resistant Strength of Injected Concrete (Rock Powder and Yellow Sand)

1. cement no.
2. cement
3. rock powder
4. yellow sand (medium)
5. oval pieces
6. maximum load (ton)
7. pressure resistant strength (kg/cm^2)
8. 7 days
9. 14 days
10. 28 days
11. 35 days
12. No. 500 <conventional>
13. same as above
14. same
15. same
16. same
17. same

FACTORS AFFECTING THE ACCELERATEDLY HARDENED INJECTED CONCRETE USING THE DRY METHOD /30

Raymond J. Schutz

Injected concrete is frequently used in engineering projects when the concrete hardening time must be accelerated and the strength must be improved. Injected concrete used in the initial protection of the ground, in areas where tide comes in and goes out, and in thick structure overhead for sealing and waterproofing, belongs to the small range of applications where accelerated hardening and early strength are required.

The use of a suitable accelerator can instantaneously bring the hardening time of concrete to normal.

There are many factors affecting the fast hardening of injected concrete. Among these factors, some of them are affecting the compounds in the Portland cement, and some are only affecting injected concrete. For any given factor or factors, whether it is important or not is determined by the materials and injection condition of the concrete, and the expected final result.

Temperature

Temperature affects the hardening time and strength of all Portland cement mixtures. Figure 1 shows the effect of temperature measured during injection on the hardening time. It shows that the hardening time could differ by approximately one fold between 24°C and 10°C. If these mixtures use the same amount of accelerators, then these mutual correlations still remain correct. In order to maintain a certain fast hardening and early strength requirements, the amount of accelerators must increase with decreasing temperature.

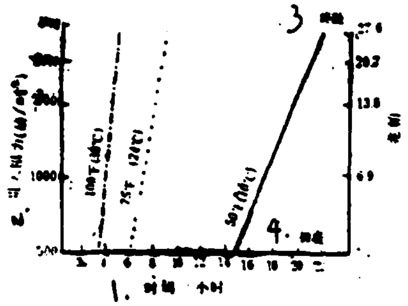

Figure 1. Effect of Temperature on Hardening Time

1. time (hour)
2. injection resistance (lb/in^2)
3. final hardening
4. initial hardening

Cement

Cements of different compositions exhibit various hardening times (Figure 2). For a given accelerator at a certain ratio, it is possible to accelerate the hardening of concrete by 50%. However, a slow hardening cement may cancel some of the accelerated hardening characteristics of the accelerator.

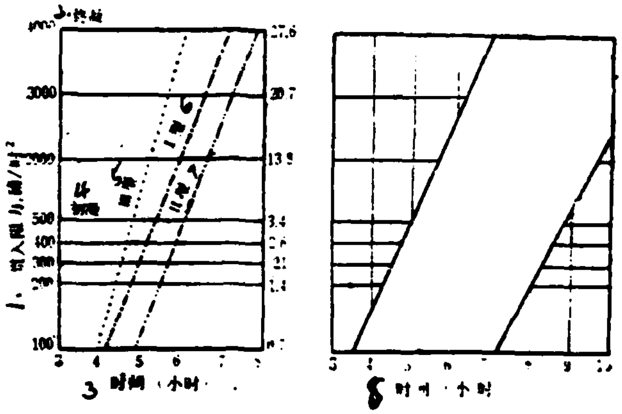

Figure 2. Hardening Times of Various Types of Cement

1. injection resistance, lb/in^2
2. final hardening
3. time (hours)
4. initial hardening
5. type III
6. type I
7. type II
8. time (hours)

FILME